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# **TRAJECTORY STUDIES FOR SATURN V CIRCULAR SYNCHRONOUS ORBITS**

**By Veit Hanssen**

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**MISSION PLANNING AND ANALYSIS DIVISION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS**

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PROJECT APOLLO

TRAJECTORY STUDIES FOR SATURN V CIRCULAR  
SYNCHRONOUS ORBITS

By Velt Hanssen  
Mission Analysis Branch

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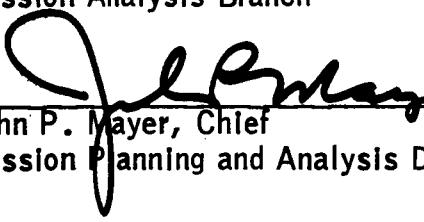
December 29, 1966

MISSION PLANNING AND ANALYSIS DIVISION  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS

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## TRAJECTORY STUDIES FOR SATURN V CIRCULAR SYNCHRONOUS ORBITS

By Veit Hanssen

### SUMMARY

A study was made on different ascent and descent profiles for an inclined, circular, synchronous orbit. Two of the four investigated ascent profiles use the S-IC and the S-II stages to insert the S-IVB/CSM configuration into an earth parking orbit (EPO) after which the first S-IVB burn raises apogee to synchronous altitude. Circularization is achieved with the second S-IVB burn alone or with the S-IVB and the service propulsion system (SPS). The other two profiles use a direct ascent approach with the second S-IVB burn being used both with and without the SPS to achieve the synchronous orbit. An analysis of some preliminary deorbit and entry data is also presented.

A comparison of the results of the study indicates that the maximum payload can be inserted by using the S-IVB and the SPS for a direct ascent to the synchronous orbit. Less payload but greater control of longitude of insertion is offered by injection to synchronous orbit from an EPO. The payload capability offered by using the EPO with the S-IVB and the SPS is 62 780 lb and with the S-IVB alone, 60 280 lb. Using the direct ascent technique, 73 750 lb of payload can be inserted into the synchronous orbit by burning both the S-IVB and the SPS. This 73 750-lb payload includes 25 800 lb for the LM laboratory and equipment for experiments. If the direct ascent is accomplished with the S-IVB alone, 69 100 lb of payload can be inserted into the synchronous orbit.

The analysis of the preliminary deorbit and entry results indicates that direct descent offers no control of the longitude of landing. However, longitude of landing can be controlled by any of several intermediate orbit schemes.

### INTRODUCTION

One of the Saturn V missions planned for the Apollo Application Program (AAP) is a 14-day synchronous earth orbital mission. A rather extensive study of this type of mission was made by North American Aviation (NAA) (ref. 1). The study was, however, based on an equatorial,

synchronous mission, and one of the three investigated profiles required two restarts of the S-IVB stage, which would be a modification from the present one-restart capability existing for the Apollo Saturn V. The remaining two profiles offered only a low payload capability.

A later study made at the Manned Spacecraft Center (MSC) (ref. 2) indicated that an inclined, synchronous orbit would result in a higher payload than the equatorial, synchronous orbit. One of the profiles allows only about 25 minutes after the second S-IVB burn for the transposition and docking (T & D) maneuver and lunar module (LM) extraction before the SPS is ignited for the synchronization burn.

The purposes of this document are to summarize results of previous studies and to examine the payload capability of an inclined, synchronous orbit using two different approaches. One uses the S-I and S-II stages to insert to EPO, followed by an S-IVB burn out of the EPO. The synchronous orbit is achieved with the second S-IVB burn alone or with the S-IVB and the SM. The second is a direct ascent approach with the second S-IVB burn being used both with and without the SPS to achieve the synchronous orbit. The latest known performance data were used for both approaches.

This document includes a brief description of the profiles and results of the previous studies and the results and analysis of the present study. An analysis of some preliminary deorbit and entry data is also included.

The payload for the synchronous orbits consists of the dry weight of the command and service module (CSM), the SPS propellant (including the propellant for deorbit), the LM laboratory, and any equipment for experiments. Only medical experiments will occur in the CSM; all other experiments will be performed in the LM laboratory, which will be modified to remove unnecessary hardware.

The groundtrack of a vehicle in an equatorial, synchronous orbit is a point, i.e., the hover point, on the equator. The groundtrack of the inclined, synchronous orbit, however, traces a figure-eight on the earth's surface because the spacecraft's velocity varies with respect to the earth.

Details of the objectives of the AAP synchronous orbit missions and of the launch vehicle and spacecraft to be used are given in the references. Scott McKay of the Mathematical Physics Branch determined the optimum trajectory for the direct ascent profiles.

## RESULTS AND ANALYSIS OF PREVIOUS SYNCHRONOUS ORBIT STUDIES

The results of the synchronous orbit studies in references 1 and 2 are summarized in table I. A cursory analysis of these results indicated that:

1. All three profiles in reference 1 and two profiles in reference 2 are equatorial, synchronous orbits which result in smaller payloads available for experiments than for inclined, synchronous orbits.
2. One of the profiles in reference 1 scheduled two S-IVB relights, which would require modification of the current S-IVB hardware.
3. Reference 2 based its first two profiles on data of the EPO of reference 1. The payload of 39 540 lb, which leaves 900 lb for experiments after subtracting the weight of the CSM and the SPS deorbit fuel, would eliminate all but the medical experiments.
4. Profile 3 in reference 2 allows only 25.6 minutes for transposition, docking, and IM extraction, which is hardly acceptable.

## RESULTS AND ANALYSIS OF PRESENT SYNCHRONOUS ORBIT STUDY

### Ascent to Synchronous Orbit

Four profiles for insertion into an inclined, circular, synchronous orbit are presented and analyzed in this section. The first two profiles use an EPO, and the last two use direct ascent to apogee at the synchronous orbit altitude. The results are summarized in tables II through VIII. Tracking stations and their equipment are presented in table IX for all four profiles.

Profile 1.- The S-IC and the S-II stages of the Saturn V insert the spacecraft into a 100-n. mi. EPO (table II). After the subsystems are checked out, the S-IVB is ignited at the optimum longitude to insure the most favorable location for the ascending node. The first burn lasts 239 seconds and raises apogee to 19 327 n. mi. After a 5.5-hour coast the spacecraft reaches apogee, and the second S-IVB burn circularizes the orbit at the synchronous altitude (19 327 n. mi.). The payload

capability of this profile is 60 283 lb. The altitude time histories during insertion and acquisition and loss of ground stations are shown in figure 1(a) for this profile. Figure 2(a) presents the groundtracks and major mission events.

Profile 2.- The launch vehicle inserts the spacecraft into the 100-n. mi. EPO (table II). Figure 1(b) shows the altitude time histories and acquisition and loss of ground stations for this profile. The first S-IVB burn to high-altitude apogee is the same as profile 1. Two injections from EPO to circular, synchronous altitude are presented for comparison in figure 2(b). After coasting to apogee, the S-IVB is relit and fires for 42 seconds until fuel depletion (4779-n. mi. perigee altitude). A 16-hour (1 revolution) coast provides sufficient time for transposition, docking, and IM extraction. The SPS is ignited near apogee, and a 283-second burn circularizes the ellipse injecting 62 779 lb of payload into synchronous orbit.

To insert the S-IVB/CSM into a 100-n. mi. EPO, using only the S-IC and S-II stages, the lift-off weight was decreased by 103 400 lb: 8400 lb of IM laboratory weight, and either 75 000 lb of S-IVB fuel and 20 000 lb of SPS propellant for profile 1 or 95 000 lb of S-IVB fuel for profile 2.

Profile 3.- The S-IC, the S-II, and part of the S-IVB are used to insert the spacecraft into a 70 by 19 638-n. mi. intermediate orbit, as shown in table III. Following a 5-hour coast, the S-IVB burns at apogee for 101 seconds, circularizing the orbit at the desired altitude. This profile inserts 69 100 lb of payload into orbit. The altitude time history during insertion and acquisition and loss of ground stations is presented in figure 1(c); figure 2(c) shows the major mission events and groundtracks for this profile.

Profile 4.- As in profile 3, the launch vehicle ascends directly into a high-apogee orbit (table IV). The S-IVB burns 401 seconds to achieve a 19 391-n. mi. apogee altitude. After a 5-hour coast, the S-IVB is reignited and burns to depletion (79 seconds), raising perigee to 10 928 n. mi. The crew then performs the transposition and docking maneuver, IM extraction, and S-IVB jettison. These maneuvers take place within 20 hours, after which the CSM reaches apogee and burns the SPS for 137 seconds to circularize the orbit at synchronous altitude. The payload capability of this profile is 73 775 lb.

From the results of the direct ascent profiles, note that the nodal point of the synchronous orbit is at  $52^{\circ}$  E for profile 3 and at  $148^{\circ}$  for profile 4.

Because all burns are S-IVB, profile 3 has no flexibility in locating synchronous orbit location. Profile 4 uses SPS for final circularization.

Waiting orbits can be used to provide synchronous orbit at other longitudes. Longitude will shift approximately  $65^{\circ}$  E for each extra orbit. Additional SPS burns could be used to provide waiting orbit periods for a finer control of longitude.

#### Descent From Synchronous Orbit

Three profiles for descent and entry from the inclined, synchronous orbit were investigated and are presented in this section. These descent profiles include a direct transfer ellipse, a phasing orbit, and a Hohmann waiting orbit. Figures 3 through 7 pertain to descent from the inclined, synchronous orbits.

Direct Transfer Ellipse.- A study was made of different direct deorbit locations along the figure-eight shaped flight path (fig. 3). The groundtrack described by the spacecraft during one period of a circular, synchronous orbit is a function of inclination and eccentricity. Since the  $28.6^{\circ}$  inclination and the 0 eccentricity are constant in all four ascent profiles, the groundtracks after insertion are identical.

The inclined, circular, synchronous orbit offers a band of deorbit locations, and touchdown can take place at any point between  $28.6^{\circ}$  N and  $28.6^{\circ}$  S latitude. The longitude of touchdown depends on the location of the line of nodes of the synchronous orbit.

The deorbit burn lasts 219 seconds and results in an SPS fuel consumption of 15 360 lb and a  $\Delta V$  of 4925 fps. The burn is followed by a 5-hour coast which brings the spacecraft to reentry altitude at 400 000 ft. At this point, the command module enters near the middle of the entry corridor with a velocity of 33 800 fps and a flight-path angle of  $-6.3^{\circ}$ . Flying at half-lift, the spacecraft touches down 9 minutes after reentry.

From SPS deorbit to the point of touchdown, the spacecraft traverses an angular distance of approximately  $188^{\circ}$ , or about  $110^{\circ}$  of longitude, as shown in figure 4.

Note that a direct deorbit from the inclined, synchronous orbit offers no control in the longitude of the landing area. Control of the latitude of landing is limited by the angle of the inclination measured north and south of the equator.

Phasing Orbit.- To control the longitude of landing, two alternatives are investigated and typical solutions presented. The descent through a phasing orbit as shown in figure 5 requires three retro-burns.

After CSM-IM separation in synchronous orbit, the SPS burns for 258 seconds, to a perigee altitude of 200 n. mi. After coasting to perigee, the SPS is reignited and burns for 66 seconds, decreasing apogee to 9000 n. mi. The spacecraft is now in a phasing orbit of 5-hour period. The angular distance traversed by the spacecraft can be changed by altering the coast time and orbital parameters of the phasing orbit. A 7-second deorbit burn at apogee gives the spacecraft the velocity necessary to enter in the middle of the entry corridor (32 074 fps - 6.1°). The total SPS propellant required for this deorbit mode is 22 850 lb.

Hohmann Waiting Orbit.- More time and less fuel consumption than for the phasing orbit technique is required by using the Hohmann waiting orbit for control of longitude of landing (fig. 6). In this mode, the spacecraft is ignited for a short impulse burn at retro attitude, which results in a perigee below synchronous altitude and a period less than that of the earth. This causes the line of nodes to precess (fig. 7) until the desired longitude for the deorbit burn is obtained. The total amount of SPS fuel for descent will range from 15 500 to 16 600 lb depending on the true anomaly of deorbit and the perigee altitude of the Hohmann ellipse.

#### CONCLUDING REMARKS

In order for a synchronous orbit mission to be feasible, there must be the capability to inject 53 000 lb of payload into the synchronous orbit. This payload includes 14 000 lb for the LM laboratory and equipment for basic experiments and 39 000 lb for the dry weight of the CSM and propellant for a direct descent deorbit. All four modes investigated in this study for injection into the inclined, circular, synchronous orbit have a payload capability exceeding the minimum requirement. However, use of a fully loaded LM laboratory, which weighs 25 800 lb (ref. 1), would eliminate ascent using the EPO for injection to the synchronous orbit.

The direct ascent to apogee at synchronous orbit altitude (profile 4) appears to offer the best combination of payload and mission flexibility. Geographic location of the synchronous orbit can be controlled by using intermediate phasing orbits because the SPS with its multiple reflight capability is used for circularization. To obtain flexibility in landing point control, intermediate, or phasing orbits must also be used during the descent.

TABLE I.- RESULTS OF PREVIOUS STUDIES

Reference profile	Launch phase			Injection into synchronous orbit		
	Ascent mode	Applied stages	Resulting orbit, n. mi.	Type of synchronous orbit	Engines burned	Payload, lb
(a) NAA Study						
1	EPO	S-IC, SII, S-IVB	100 x 100	Equatorial	Two burns of S-IVB, SPS	64 000
2	EPO	S-IC, SII	100 x 100	Equatorial	S-IVB, SPS	55 300
3	EPO	S-IC, SII, S-IVB	100 x 100	Equatorial	S-IVB, SPS	39 700
(b) MSC Study						
1	EPO	S-IC, S-II, S-IVB	100 x 100	Equatorial	S-IVB, SPS	39 543
2	EPO	S-IC, S-II, S-IVB	100 x 100	Equatorial	S-IVB, SPS	39 543
3	Direct	S-IC, S-II, S-IVB	136 x 19 240	Inclined	S-IVB, SPS	71 360
4	Direct	S-IC, S-II, S-IVB	136 x 19 240	Inclined	S-IVB, SPS	71 360

TABLE II.- TIME HISTORY OF LAUNCH VEHICLE FROM LIFTOFF TO S-II JETTISON FOR PROFILE 1 AND 2

Event	Time, sec	Longitude, deg	Geodetic latitude, deg	Altitude, ft	Inertial velocity, fps	Flight path angle, deg	Azimuth, deg
Lift-off	0.0	-80.6	28.6	0	1 340	0.0	90
End vertical rise, begin zero-lift flight	12.00	-80.6	28.6	547	1 343	4.1	90
Shutdown of S-IC inboard engine	154.57	-79.8	28.6	199 408	8 864	20.6	90
Shutdown of S-IC outboard engines, begin coast	158.57	-79.7	28.6	212 056	9 327	20.1	91
Jettison of S-IC, S-II ignition, begin pitch-up maneuver	162.37	-79.7	28.6	224 034	9 286	19.5	91
End pitch-up maneuver, change mixture ratio	172.37	-79.4	28.6	25 309	9 446	18.2	91
Jettison S-IC/S-II inter-stage adapter section	188.57	-79.0	28.6	300 147	9 748	16.3	91
Jettison launch escape system	193.57	-78.9	28.6	313 694	9 848	15.8	91
Change mixture ratio	-532.88	-69.6	28.1	617 950	19 592	0.3	96
Shutdown of S-II, begin coast	-534.88	-63.9	27.4	616 821	25 567	0.0	99
Jettison S-II	538.99	-63.4	27.3	616 800	25 610	0.0	99

TABLE III.- TIME HISTORY OF LAUNCH VEHICLE FROM LIFTOFF TO S-II CUTOFF FOR PROFILE 3

Event	Time, sec	Longitude, deg	Geodetic latitude, deg	Altitude, ft	Inertial velocity, fps	Flight-path angle, deg	Azimuth, deg
Lift-off	0.0	-80.6	28.6	0	1 340	0.0	90
End vertical rise, begin zero-lift flight	12.00	-80.6	28.6	498	1 343	1.1	90
Shutdown of S-IC inboard engine	154.57	-79.9	28.6	186 366	8 495	19.7	90
Shutdown of S-IC outboard engines, begin coast	158.57	-79.7	28.6	198 013	8 930	19.3	90
Jettison of S-IC, S-II, ignition, begin pitch-up maneuver	162.37	-79.6	28.6	209 016	8 891	18.6	90
End pitch-up maneuver, change mixture ratio	164.9	-79.6	28.6	216 066	8 923	18.3	91
Jettison S-IC/S-II inter-stage adapter section	188.57	-79.1	28.6	277 965	9 327	15.1	91
Jettison launch escape system	193.57	-79.0	28.6	289 909	9 421	14.4	91
Change mixture ratio	442.76	-70.1	28.1	493 101	18 172	-.76	96
Shutdown of S-II, begin coast	536.23	-64.8	27.5	460 485	23 361	9.4	99

TABLE IV.- TIME HISTORY OF LAUNCH VEHICLE FROM LIFTOFF TO S-II CUTOFF FOR PROFILE 4

Event	Time, sec	Longitude, deg	Geodetic latitude, deg	Altitude, ft	Inertial velocity, fps	Flight- path angle, deg	Azimuth, deg
Lift-off	0.0	-80.6	28.6	0	1 340	0.0	90 -
End vertical rise, begin zero-lift flight	12.00	-80.6	28.6	498	1 343	1.1	90
Shutdown of S-IC outboard engine	154.57	-79.9	28.6	186 366	8 495	19.7	90
Shutdown of S-IC outboard engines, begin coast	158.57	-79.7	28.6	198 013	8 930	19.3	90
Jettison of S-IC, S-II, ignition, begin pitch- up maneuver	162.37	-79.6	28.6	209 016	8 891	18.6	90
End pitch-up maneuver, change mixture ratio	164.9	-79.6	28.6	216 067	8 922	18.3	91
Jettison S-IC/S-II inter- stage adapter section	188.57	-79.1	28.6	278 041	9 323	15.1	91
Jettison launch escape system	193.57	-79.0	28.6	290 018	94 162	14.5	91
Change mixture ratio	442.76	-70.2	28.1	500 646	180 887	-.6	96
Shutdown of S-II, begin coast	536.23	-64.8	27.5	469 984	23 231	-.75	98

TABLE III. - TIME SEQUENCE OF EVENTS FOR PROFILE 1.

Event	Time Data			Spacecraft Location			Inertial Velocity Vector			Propellant, lb.	$\Delta V$ , fps	Weight of Spacecraft, lb.
	Hr.	Min	Sec	Duration, Sec	Longitude, deg	Geodetic latitude, deg	Altitude, n.mi.	Velocity, fpm	Flight path, deg	Azimuth, deg		
Coast in EPO	00	08	53	-64.0	27.4	101	25 568	-0.024	98.8			257 686
1st S-IVB Burn	00	26	51	239	2.8	0.0	25 593	-0.056	118.5	114 575	8100	
Coast 5 hours	00	30	50		18.2	-8.8	125	33 507	4.187	117.3		143 111
2nd S-IVB Burn to circularize orbit	05	42	38	89	111.1	4.1	19 327	5.241	.543	61.8	42 528	
S-IVB/CSM separation	05	44	07		110.9	4.2	19 327	10.086	.0	61.8		100 583
Transposition and docking	05	52	07		110.6	5.6	19 327	10.086	.0	62.0		60 283

TABLE IV.- TIME SEQUENCE OF EVENTS FOR PROFILE 2.

Event	Time Data			Spacecraft Location			Inertia Velocity Vector			Propellant, lb.	Resulting Perigee/Apogee n.mi.	$\Delta V$ fps	Weight of Spacecraft, lb.	
	Hr	Min	Sec	Dura- tion, Sec	Geo- graphic Latitude, deg.	Longi- tude, deg.	Altitude, n.mi.	Velocity, fps	Flight path, deg	Azimuth, deg				
Coast in EPO	00	08	53	-64.0	27.4	101	25 568	.025	98.8	114 651	107/19 400	8108	257 686	
1st S-IVB Burn	00	13	28	239	-45.0	22.3	100	25 571	-.056	107.4	114 651	107/19 400	8108	
Coast 5 hours:	00	17	27		-27.6	16.5	129	33 491	4.155	113.7				114 651
2nd S-IVB Burn to fuel depletion	05	29	33	42	64.3	-20.2	19 327	5 240	.535	69.4	20 349	4 779/19 327	2124	
Coast 1 period perform transposition and docking	05	30	15		64.2	-20.1	19 327	7 348	.557	69.4				
Burn SPS to Circularize orbit	18	57	41	285	-137.9	-20.0	19 327	7 348	.0	69.3	19 553	19 327/19 327	2741	
Payload Inserted into synchronous orbit	18	59	40		-138.0	-19.9	19 327	10 086	.0	69.0				62 779

TABLE VII. - TIME SEQUENCE OF EVENTS FOR PROFILE 3.

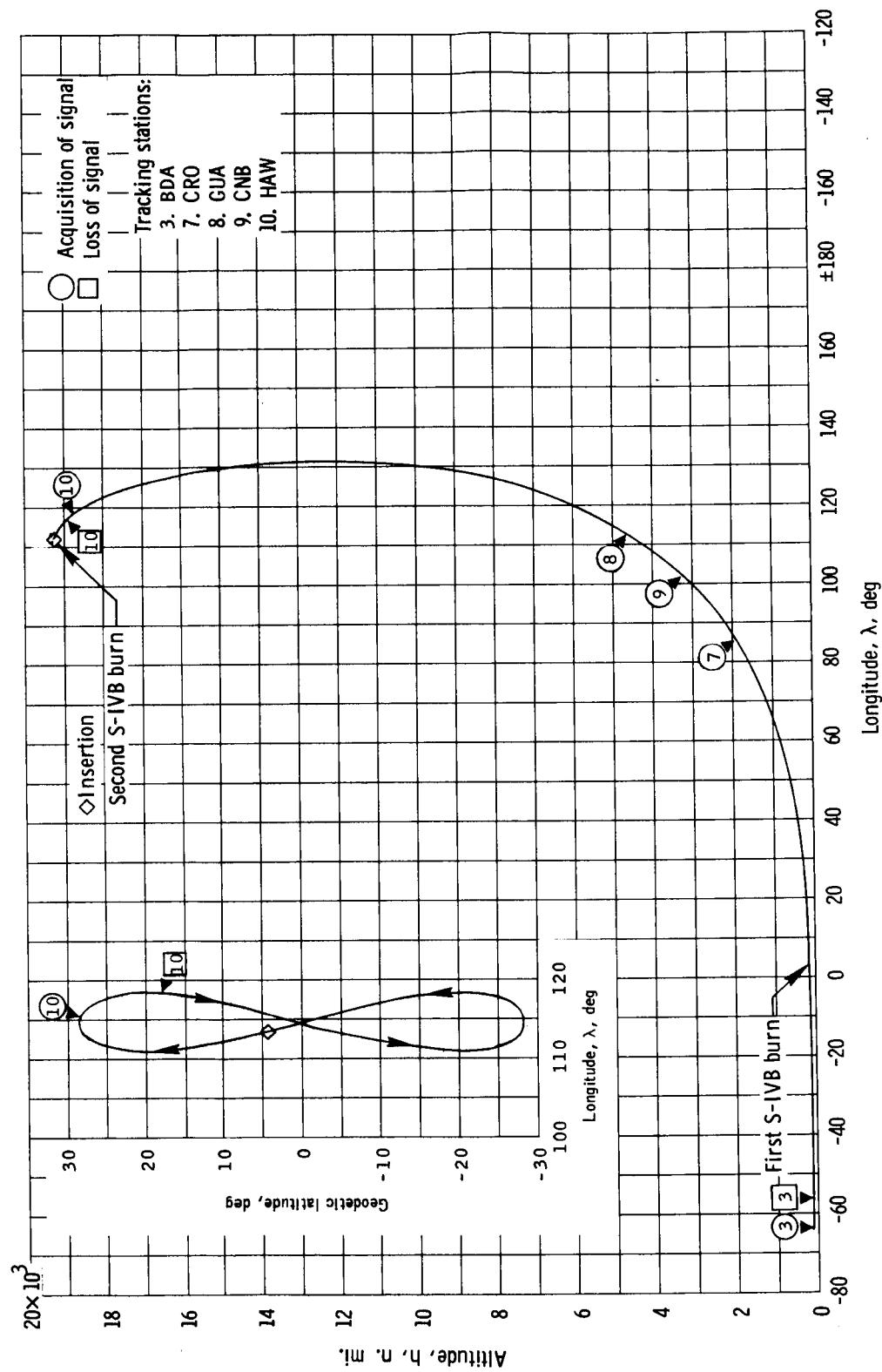
Event	Time Data			Spacecraft Location			Inertial Velocity Vector		Propellant, lb	$\Delta V$ , fps	Weight of Spacecraft, lb
	Hr	Min	Sec	Duration, Sec	Longitude, deg	Geodetic Latitude, deg	Altitude, n.mi.	Velocity, fps	Flight path, deg	Azimuth, deg	
Coast between burns	00	08	56	-64.8	27.5	76	23 361	-736	98.5	180 792	338 537
1st S-IVB Burn	00	09	27	346	-62.8	27.2	74	23 972	-847	99.5	9670
Coast to apogee	00	15	13	-36.5	20.1	105	33 642	5.223	110.8		157 746
2nd S-IVB Burn to circularize orbit	04	52	46	100	55.9	-25.3	19 327	5 370	13.565	48 318	5043
S-IVB/CSM separation	04	54	26	55.8	-25.8	19 327	10 086	0.0	76.0		109 428
Transposition and docking	05	02	26	55.9	-24.7	19 327	10 086	0.0	75.1		69 100

TABLE VIII. - TIME SEQUENCE OF EVENTS FOR PROFILE 4.

Event	Time Data			Spacecraft Location			Inertial Velocity Vector		Propellant, lb	$\Delta V$ , fps	Weight of Spacecraft, lb
	Hr	Min	Sec	Duration, Sec	Longitude, deg	Geodetic Latitude, deg	Altitude, n.mi.	Velocity, fps	Flight path, deg	Azimuth, deg	
Coast between burns	00	08	54	-65.0	27.5	79	22 950	-698	98.4	192 307	353 537
1st S-IVB Burn	00	08	56	384	-64.9	27.5	79	22 977	-698	98.4	10 730
Coast 5 hours	00	15	37	-35.6	19.8	89	33 706	3.852	111.3		161 229
2nd S-IVB burn to fuel depletion	00	25	15	87	57.0	-22.9	19 327	5 218	1.233	37 693	3 671
Coast 1 period	05	26	34	56.9	-22.8	19 324	8 875	.131	72.1		83 235
Burn SPS to circularize	23	04	06	79	151.8	-19.9	19 329	8 875	.140	9 459	19 327/19 327
Payload inserted into synchronous orbit	23	06	23	151.8	-22.7	19 327	10 086	0.0	71.9		73 775

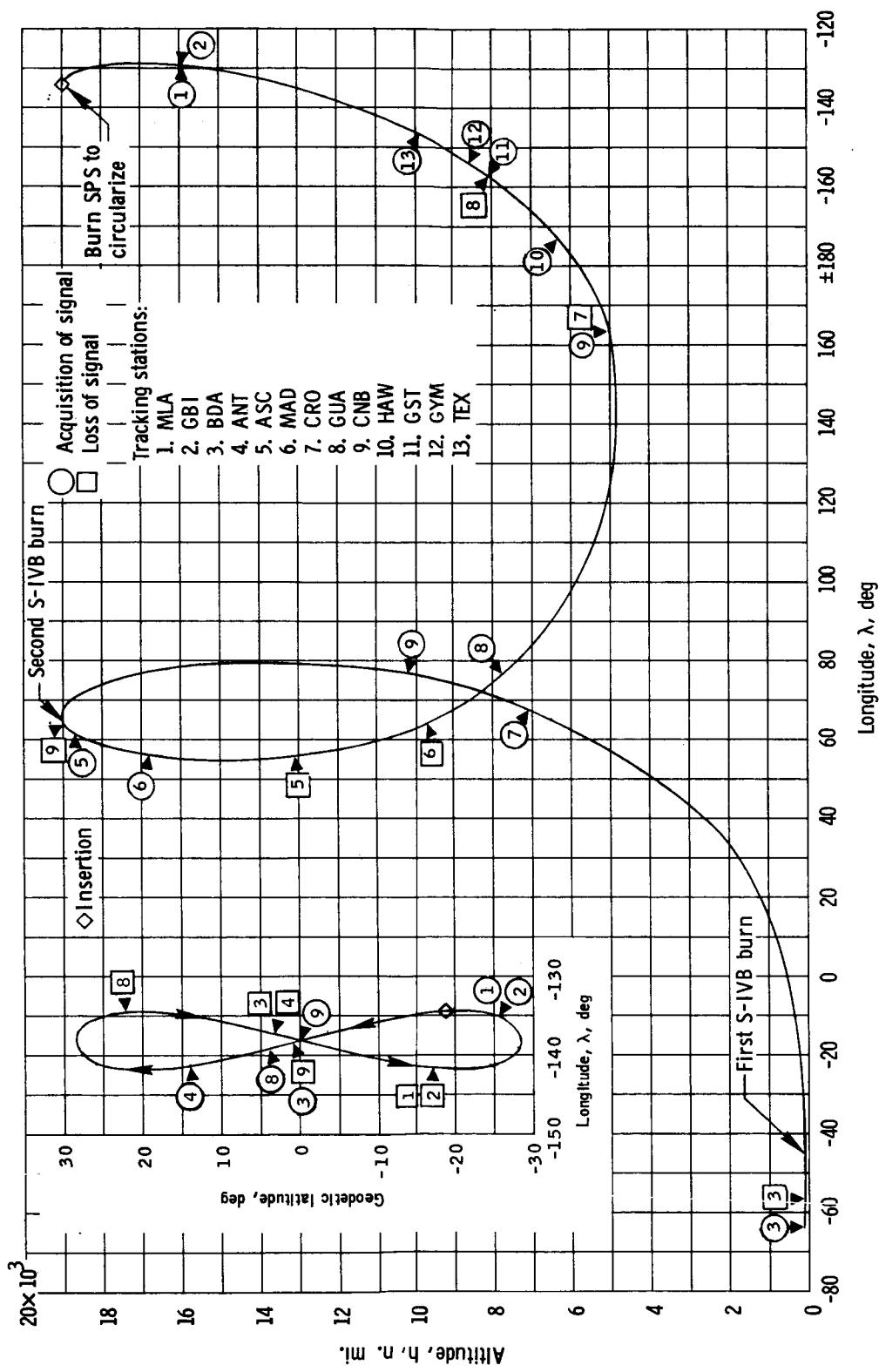
TABLE IX .-- UNIFIED S-BAND STATIONS  
AND THEIR LOCATIONS

Station name	Call letters	Geodetic latitude, deg	Longitude, deg
Merritt Island	MLA	28.50	-80.52
Grand Bahama	GBI	26.65	-78.15
Bermuda	BDA	32.35	-64.65
Antigua	ANT	17.01	-61.75
Ascension Island	ASC	-7.95	-14.32
Madrid	MAD	40.45	-4.16
Carnarvon	CRO	-24.9	113.72
Guam	GUA	13.30	144.73
Canberra	CNB	-35.5	148.97
Hawaii	HAW	22.12	-159.66
Goldstone	GST	35.34	-116.87
Guaymas	GYM	27.96	-110.72
Corpus Christi	TEX	27.65	-97.37



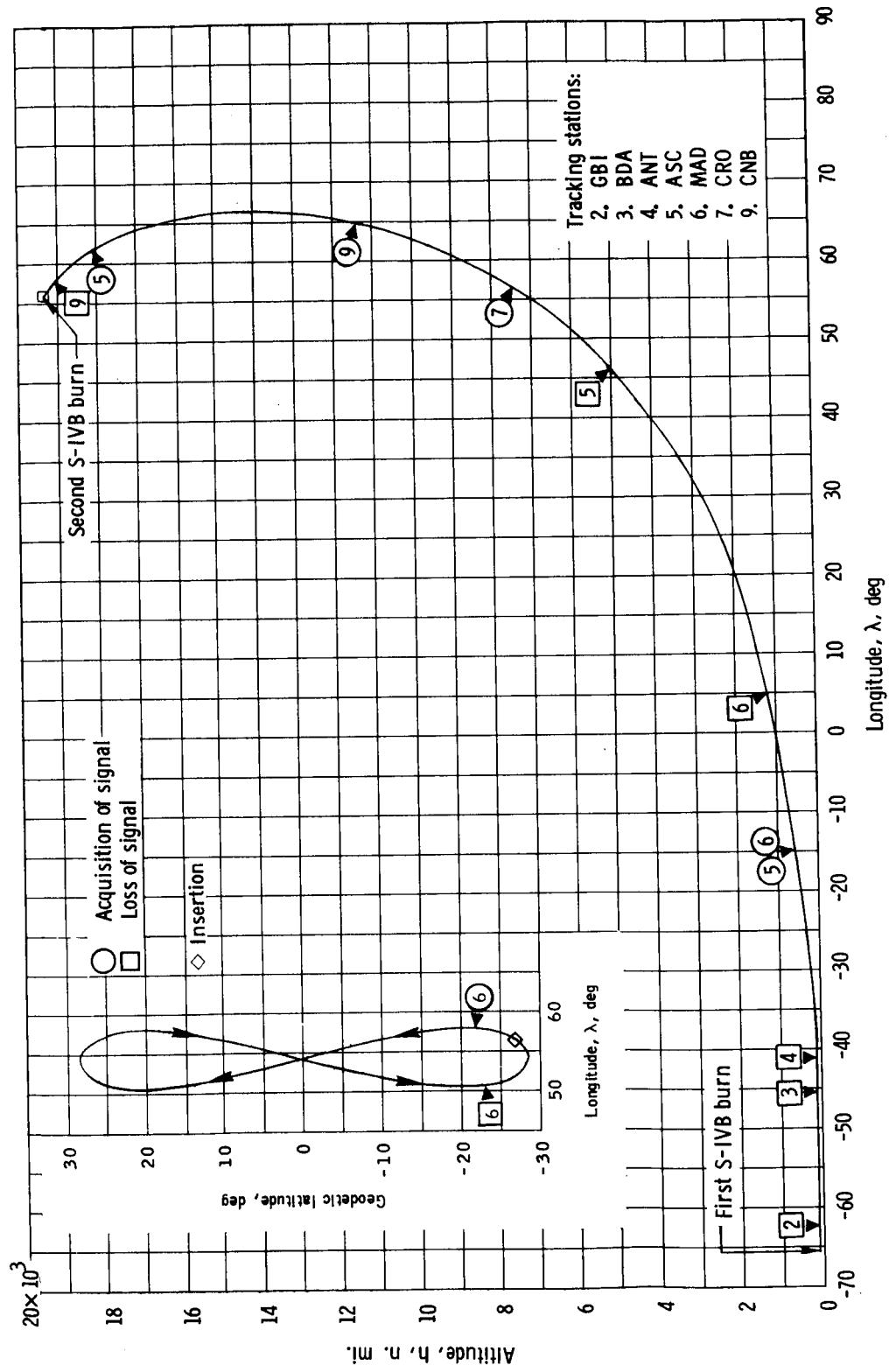
(a) Profile 1. Earth parking orbit and injection into synchronous orbit by S-IVB.

Figure 1.- Ascent to insertion into synchronous orbit.



(b) Profile 2. Earth parking orbit and injection into synchronous orbit by S-IVB and SPS.

Figure 1. - Continued.



(c) Profile 3. Direct ascent into synchronous orbit by S-IVB.

Figure 1. - Continued.

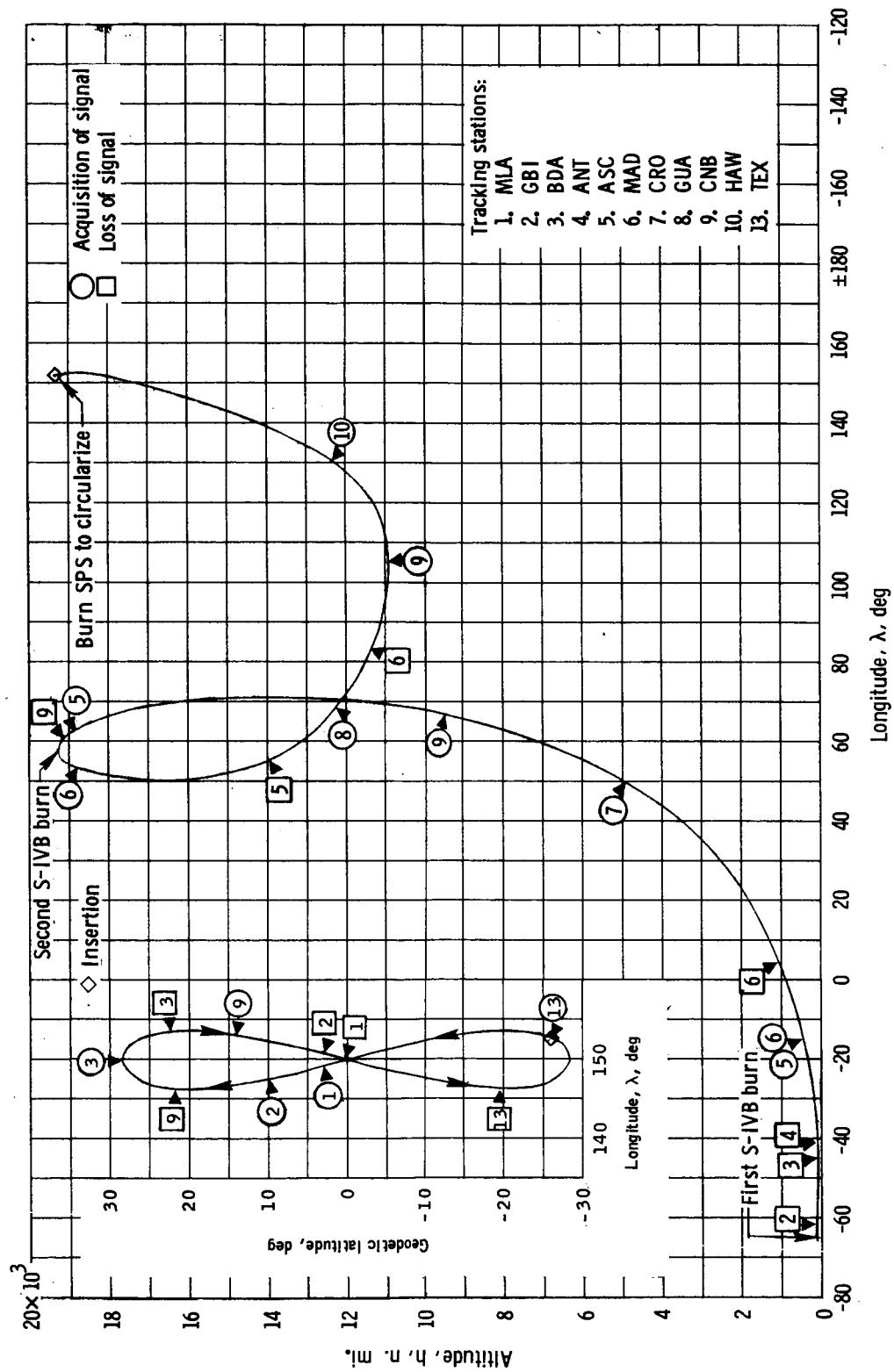
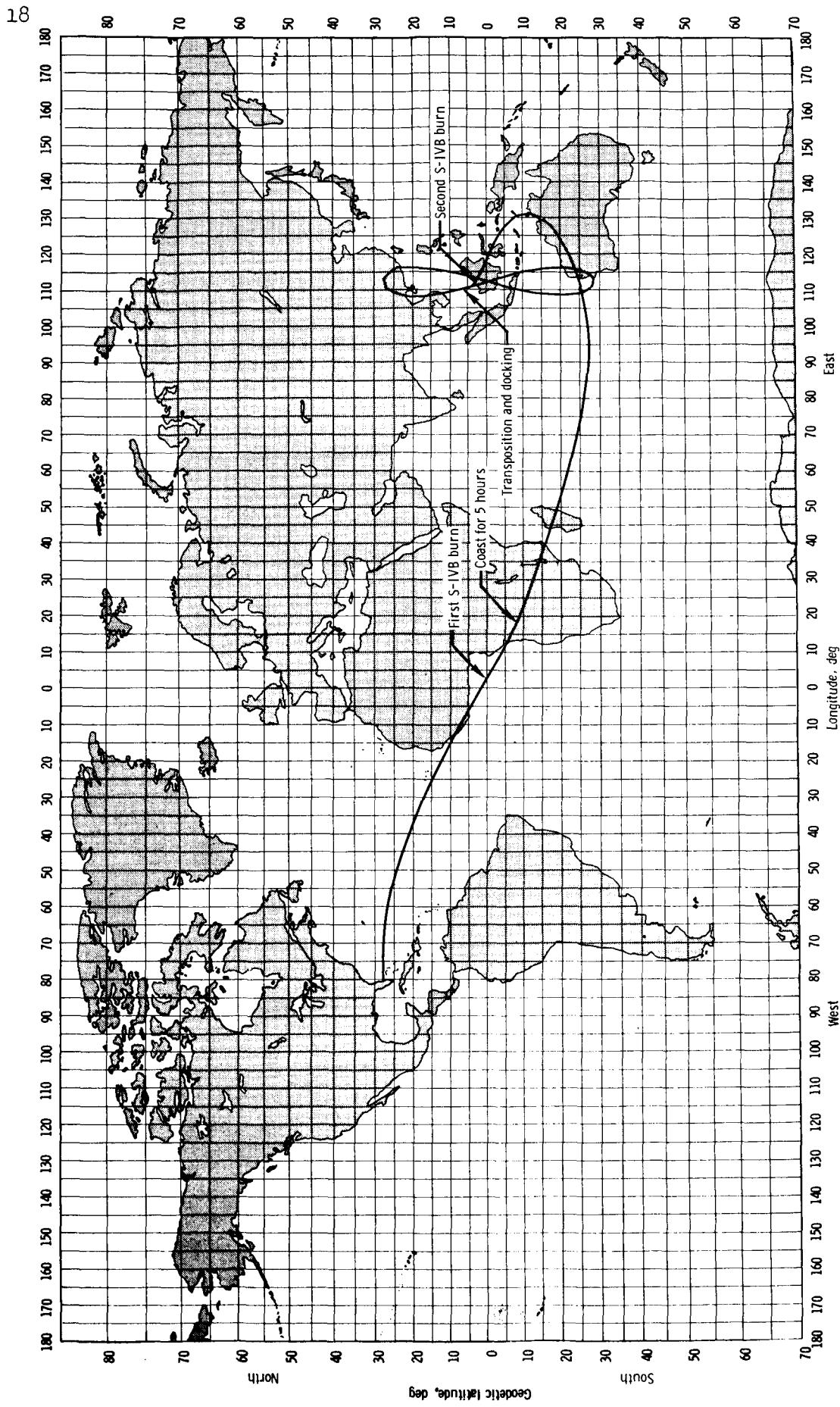
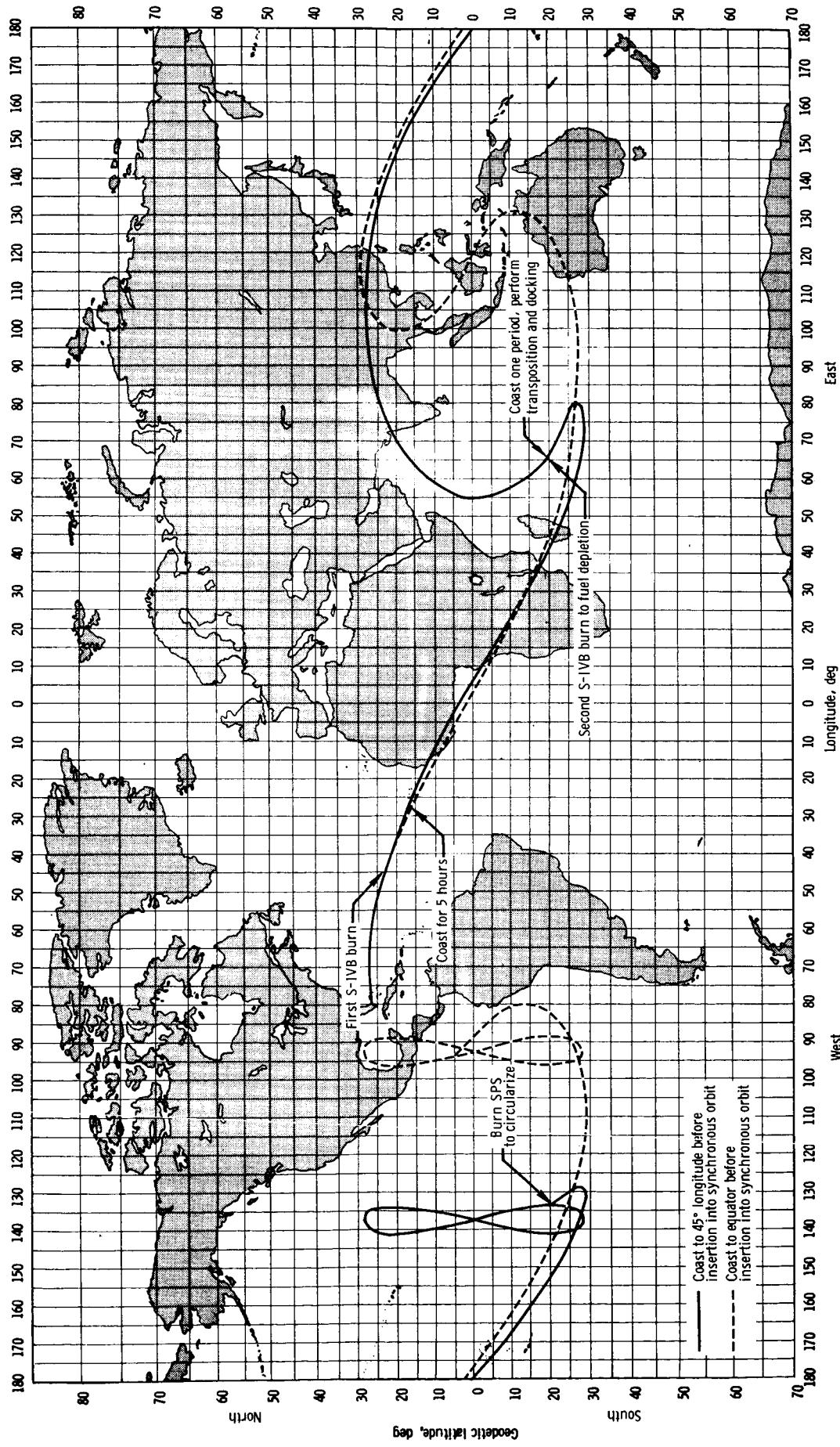


Figure 1. - Concluded.

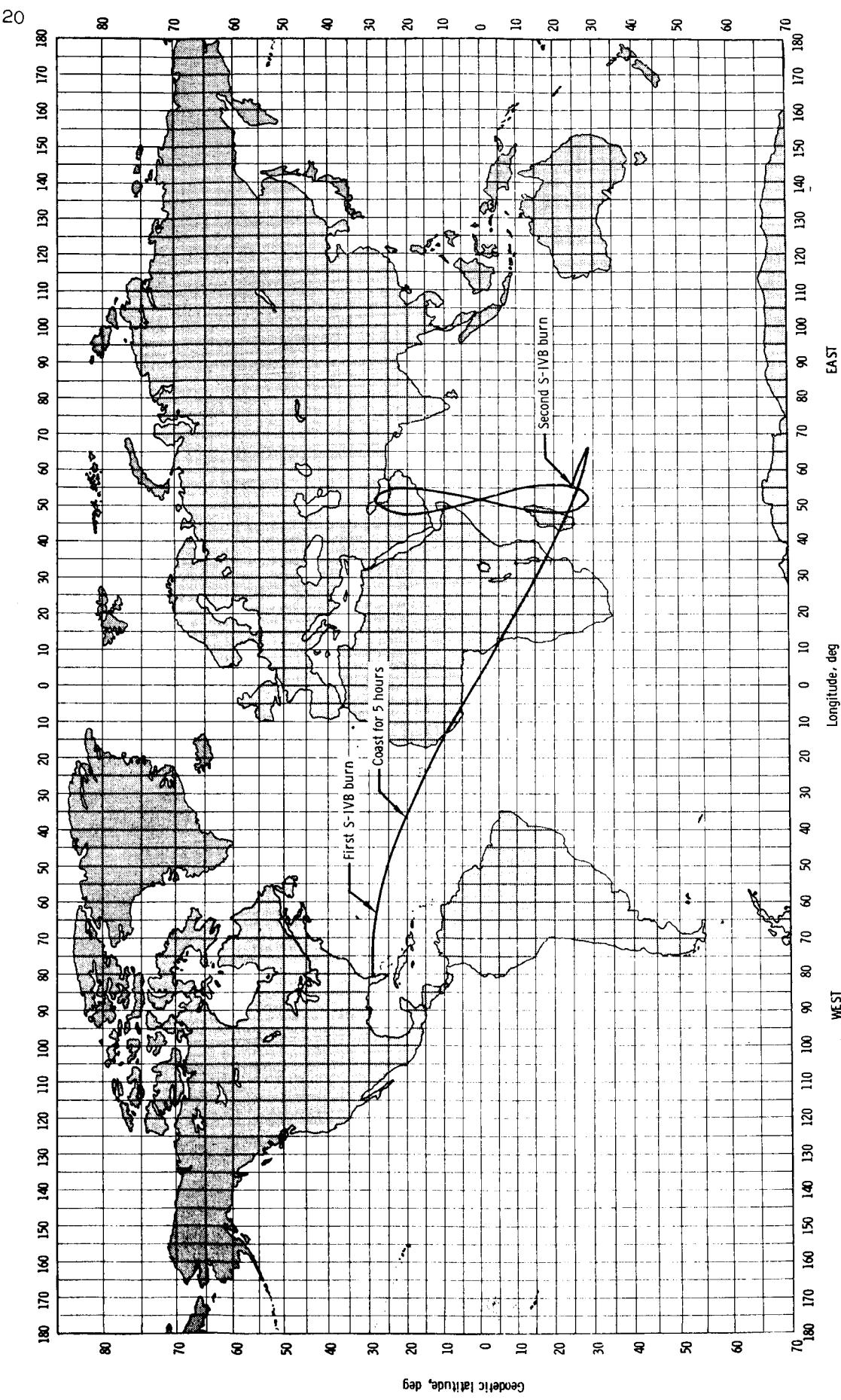


(a) Profile 1. Earth parking orbit and injection into synchronous orbit by S-IVB.

Figure 2. - Groundtrack and major mission events.

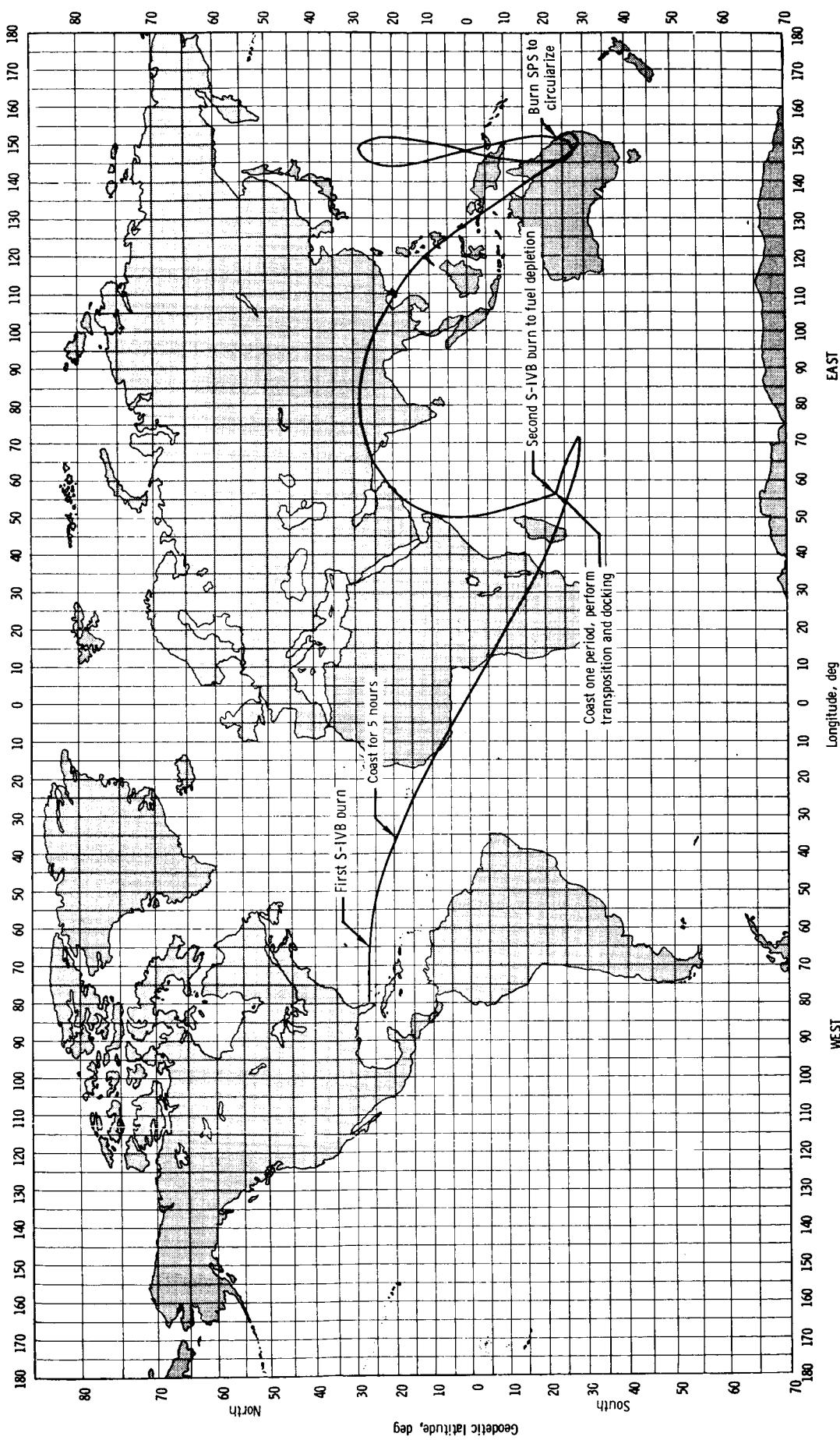


(b) Profile 2. Earth parking orbit and injection into synchronous orbit by S-IVB and SPS.



(c) Profile 3. Direct ascent into synchronous orbit by S-IVB.

Figure 2 - Continued.



(d) Profile 4. Direct ascent into synchronous orbit by S-IVB and SPS.

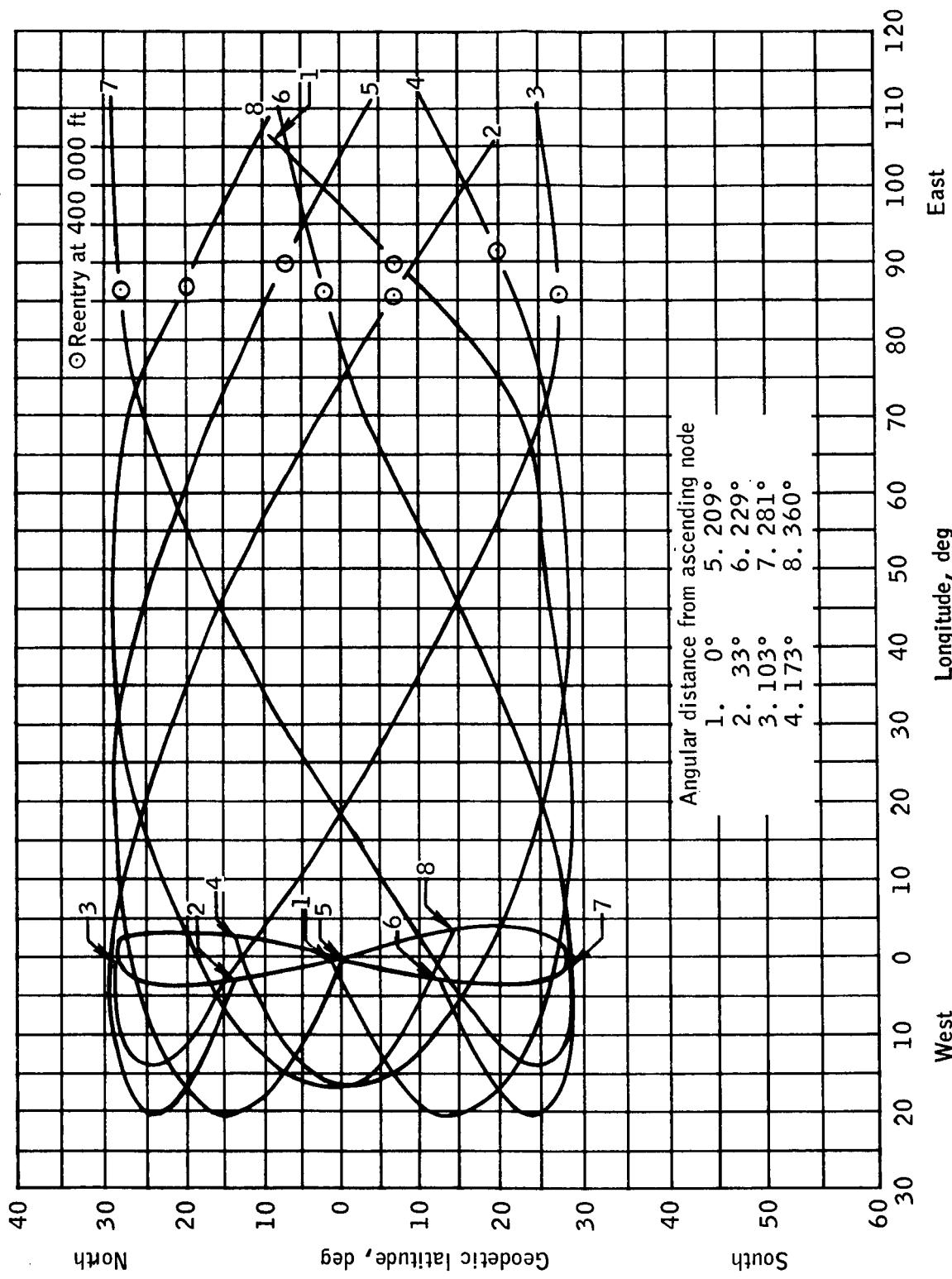


Figure 3. - Direct descent from circular, inclined, synchronous orbit.

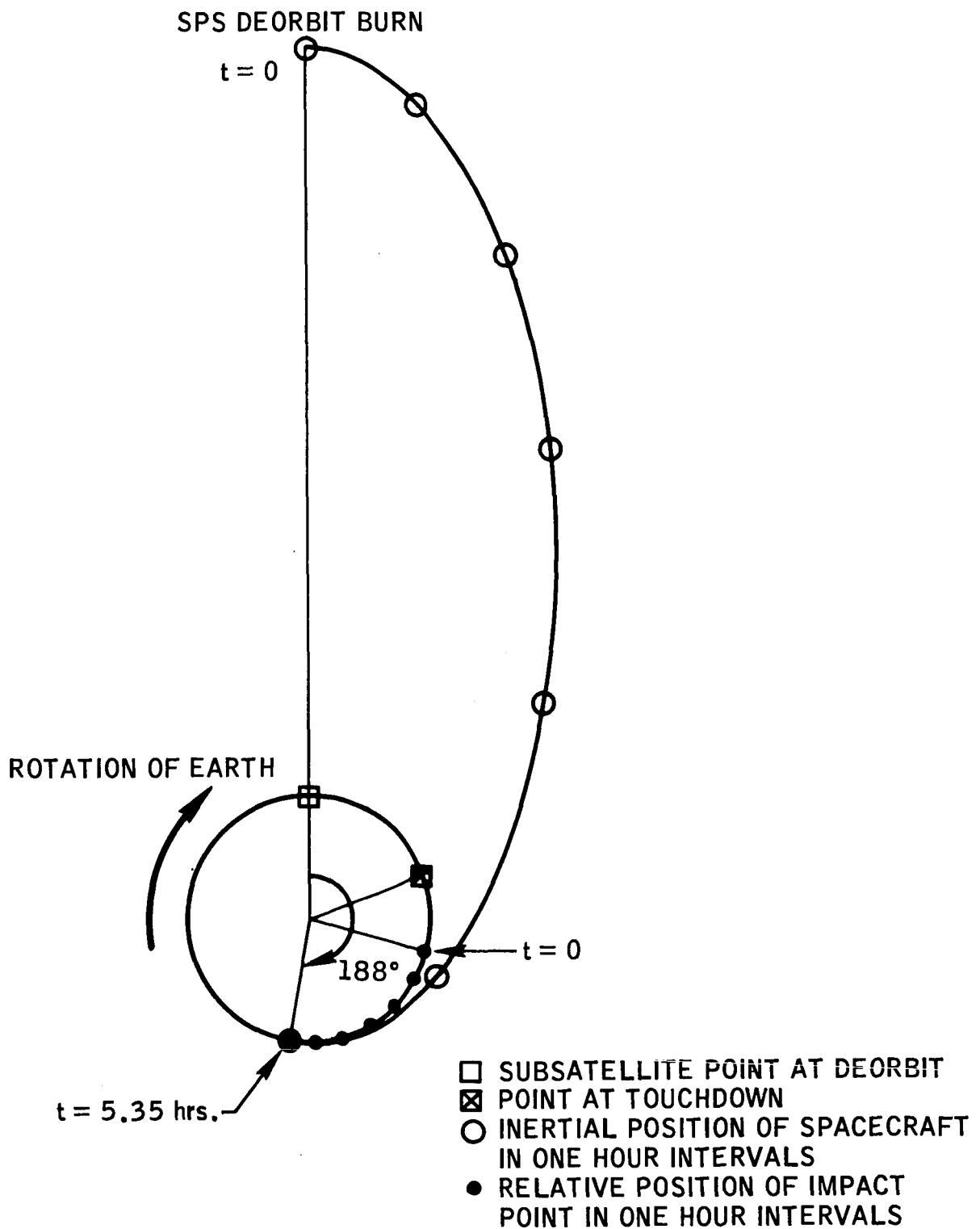


Figure 4.- Central angle for deorbit from synchronous altitude.

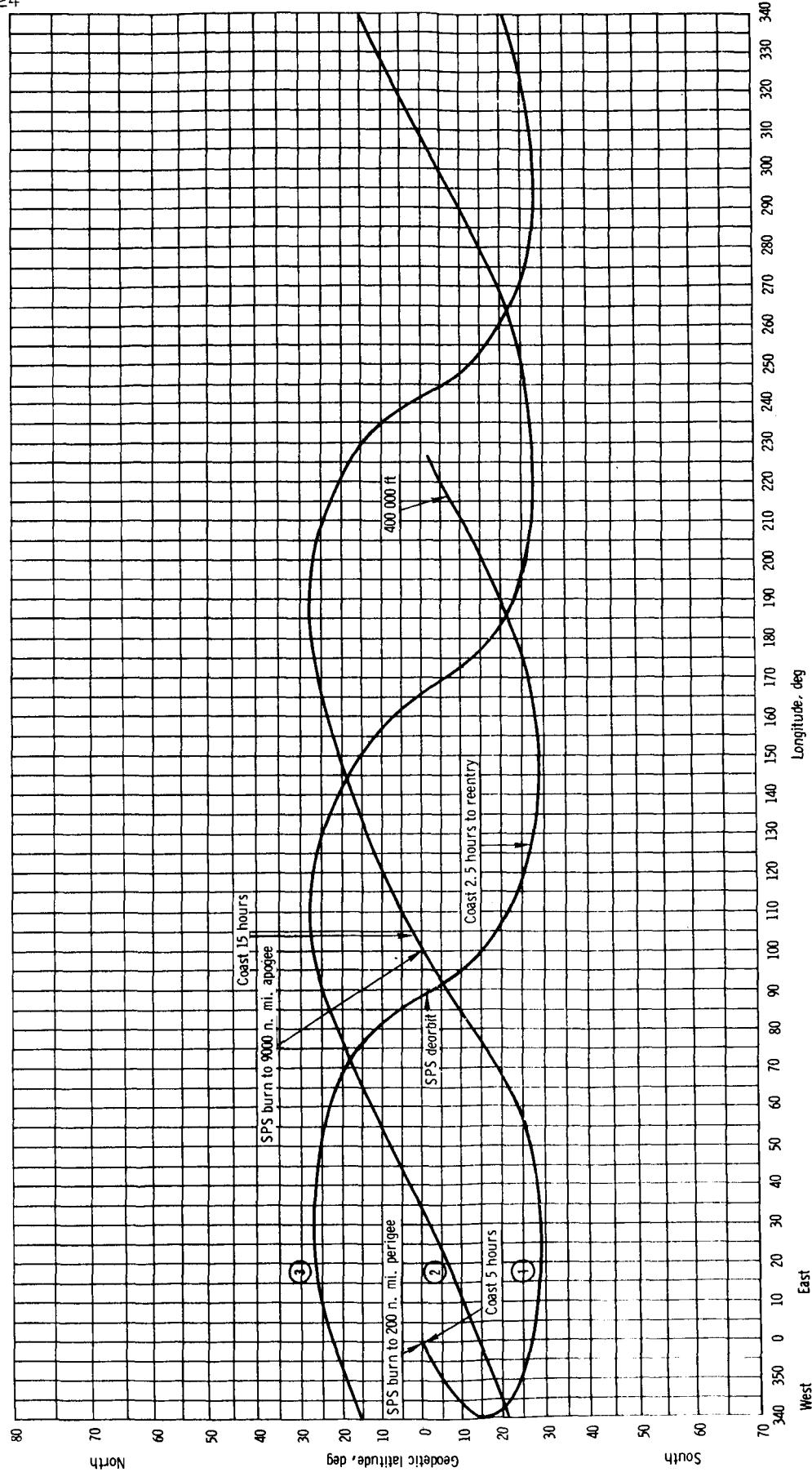


Figure 5. - Descent through phasing orbit.

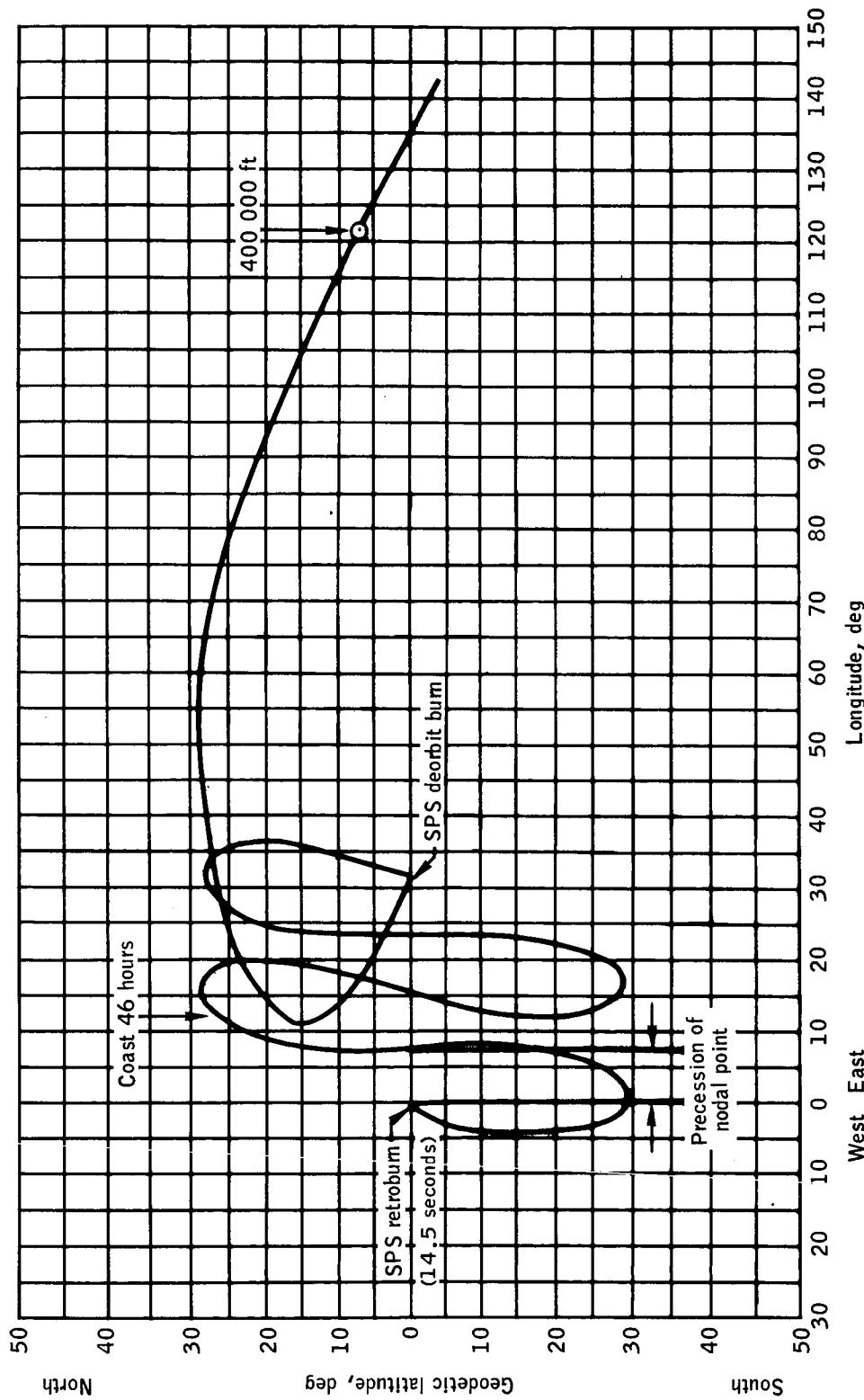


Figure 6. - Descent from Hohmann waiting orbit.

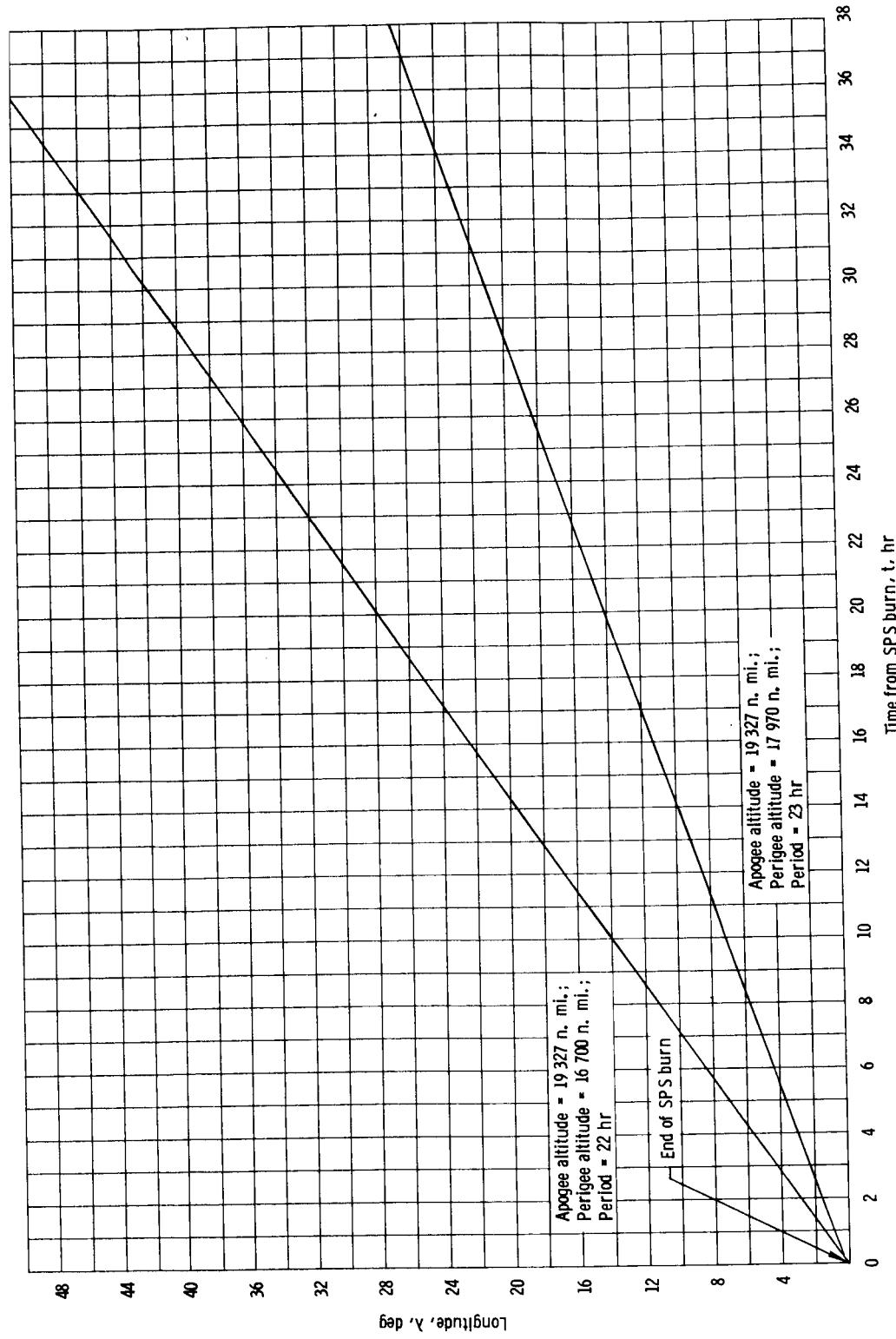


Figure 7. - Precession of nodal point at different Hohmann waiting orbits (See Figure 6).

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